6 Analysis

Vertical Velocity Profile

In addition to the physical model data on vertical velocity profile, the Kampsville prototype data from meters 998, 999, and 1000 were analyzed for vertical profile changes. The number of events where all three meters were functioning was limited; trip 2 did not have enough events to be useful. Maximum return velocity was determined from the ISWS report by taking the difference between the impact and the ambient velocity. Only those events producing a maximum return velocity of 0.1 m/sec or greater were used in the analysis because lesser values are difficult to separate from ambient velocity. For trip 1 conditions, meter 998 was 0.31 m above the bottom, meter 999 was 1.22 m above the bottom, and meter 1000 was 2.44 m above the bottom at a location where the local depth was about 3.4 m.

Results from the physical model and the prototype data in Table 56 suggested the flow depth can be separated into two zones: (a) an upper zone where the velocity change due to vessel-induced return velocity is nearly uniform, and (b) a lower zone where the changing boundary layer tends to limit the maximum tow-induced return velocity. The dividing zone between the two is probably not a fixed percentage of the depth but depends on channel boundary layer growth, which in turn, depends on vessel speed and length, return velocity magnitude, boundary roughness, local depth, and ambient velocity magnitude. From the model and prototype tows where vertical distribution was measured, the return velocity change at the position farthest from the bed was treated as being in the upper zone and used to normalize velocities measured at all positions closer to the bed. Upbound and downbound prototype data near the bed were highly variable. For the upbound tows shown in Table 56, the velocity profile is uniform except for the meter located at 0.31 m above the bed. This suggests that the dividing line between the upper and lower zones is somewhere between 0.31 and 1.2 m above the bed. For downbound tows, the profile has a similar but greater reduction near the bed but also has a peak at a point about 1 m above the bed that is not found in the upbound data. In either case the use of measured velocities at 60 percent of the local depth below the water surface captures close to the maximum tow-induced return velocity.

Upbound/Downbound/Influence of Ambient Currents

Data from pool el 418.0, pool el 419.4, and pool el 427.0 are plotted in dimensionless form in Figures 85-98. Velocities are normalized by dividing by the Schijf average return velocity computed using the vessel speed relative to the water and the effective draft.

One question that must be answered in development of analytical models of tow effects is how do tow-induced currents add or subtract from ambient currents for upbound and downbound tows? At present, analytical models assume that tow currents add directly to ambient currents. For example, return current from the tow is added to ambient current for an upbound tow and subtracted from the ambient current for downbound tows. Tow speed relative to the water is presently determined by vessel speed over the ground minus (for downbound) or plus (for upbound) the average channel velocity. The question then is should the velocity near the tow, rather than the average channel velocity, determine the vessel speed relative to the water for use in analytical models? To evaluate this hypothesis, tow events were plotted where upbound and downbound tows had the same or nearly the same speed relative to the water. Results for events with similar speeds are shown in Figures 85-90 and 93-96. Results show that adding and subtracting from ambient flows produces similar results for pool el 418.0 and 419.4 experiments in Figures 85-90. Three of the four pool el 427.0 experiments in Figures 93-96 show the average return velocity for the upbound tows higher than return velocity for downbound tows for one channel side. The conclusion on the correct addition of ambient currents will await further data collection in the Clark's Ferry physical model.

Normalized Velocity Distribution

A second issue in development of the analytical model is developing a dimensionless or "unit" time-history of the return velocity. In the analytical model, equations predict the maximum return velocity during vessel passage. This maximum return velocity is the basis for normalized time-histories of return velocity. Return velocity was normalized by first subtracting the ambient velocity and then dividing by the maximum return velocity. Time was normalized by dividing by the time required for barge passage defined as total barge length/vessel speed relative to the ground. Prototype, physical model, and numerical model return velocities were normalized using this procedure and are shown in Figure 99. Proto- type data from the six verification tows were averaged to develop the empirical time history in Figure 99. Meter 999 was used from the prototype data because its vertical position relative to the bed is similar to this study's physical model experi- ments where the meters were positioned 60 percent of the local depth below the water surface. The three upbound tows and the three downbound tows from the prototype experiments showed no significant difference when normalized using this procedure. The physical model experiments used to develop the average normalized curve were (a) the upbound KLU335C, KLU488C, KLRU49C, and KLLU49C; and (b) the downbound KLLD51C and KLRD49C. All physical model analysis used the probe closest to prototype meter 999. The numerical model curve was based on the *William C. Norman* tow using the position closest to meter 999. The physical model and prototype data differ only near the bow of the tow where the physical model experiences a significant bow velocity not observed in the prototype for reasons previously discussed. The numerical model reaches a peak return velocity earlier in the tow event and departs from the prototype and physical model after tow passage, possibly related to the absence of propellers.

Data Variability

The nine *William C. Norman* physical model experiments (Table 54) were used to determine the standard deviation of the maximum return velocity. The maximum return velocity was determined for each experiment by taking the difference between the ambient and the maximum impact. The standard deviation was determined for each probe based on the nine replicates. The average standard deviation for the eight probes was 12 percent of the maximum return velocity. For example the nine replicates from probe 6 had an average maximum return velocity of 0.234 m/sec. The standard deviation of the nine probe 6 replicates was 0.12(0.234) = 0.028 m/sec.

7 Summary and Conclusions

Ambient flow conditions in both the physical model and the prototype had significant variations at a large range of frequencies including the frequency at which the tow effects occur. A fast Fourier transform filtered information above 0.02 Hz.

Prototype return velocity and drawdown compared to physical model return velocity and drawdown in the Kampsville site showed that the Froude model with geometric scaling of vessel size resulted in model values greater than the prototype. The physical model draft had to be reduced from purely geometric scaling for agreement between model and prototype. The physical model also generated a wave and flow at the bow greater than the prototype data. This bow effect was likely related to the rapid acceleration that must be used in the physical model because of the limited flume length.

Variability of return velocity was evaluated using nine identical experiments in the physical model. The standard deviation of the maximum return velocity was 12 percent of the maximum return velocity.

Rake angle experiments determined the effect on return velocity and drawdown. It appears from Figures 34-38 that values for drawdown and return current are consistently higher for 0.16 rad (90 deg) than 0.05 rad (26 deg). Further conclusions will await additional experiments on the Clark's Ferry physical model.

Experiments were conducted using a stationary boat in a flow moving at the speed of the vessel, which changed a dynamic event to a steady one making measurements much easier. However, the rough water surface present when simulating high vessel speeds makes this form of experimenting questionable.

The vertical profile of return velocity change was investigated to determine how to interpret and compare return velocities taken at different distances from the bottom. During passage of a tow, the flow depth can be separated into a lower zone in which boundary layer growth can inhibit maximum return velocity and an upper zone in which the return velocity is nearly uniform. The lower zone is generally confined to the lower 0.5 m of the depth.

Experiments were conducted to determine the influence of upbound versus downbound tows relative to variable magnitudes of ambient currents. For low ambient currents, influences were negligible.   Further conclusions regarding this issue will await additional data from the Clark's Ferry model.

A normalized return velocity time-history was developed for future use in analytical models that require the time-history of vessel changes. The magnitude of return velocity was normalized by the maximum return velocity, and time was normalized by the time required for the barges to pass a given point.

A numerical simulation using the HIVEL-2D model assessed the flume length adequacy as well as comparing return velocity and drawdown from the prototype, the physical model, and the numerical model. Numerical simulations of the physical model flume and of a much longer reach with the same cross section (over the entire length) as the experiment section showed that the 61-m-long experiment section in the physical model resulted in return velocity and drawdown equal to long river reaches. The return velocity magnitude in the numerical model and the prototype *William C. Norman* were compared. The maximum return velocity from the numerical model was 9 percent greater than the prototype based on the average of results at five velocity meters.

A large body of far field physical forces data in the form of return velocity and drawdown form were developed in this study. These data are available for future development of analytical models and for numerical model verification.